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A Photo-Grid Technique for Sheet Metal Elongation Measurements

With the use of higher strength sheet metal in the aircraft industry, interest in the formability of sheet has increased markedly, since processes that improve strength frequently reduce the ductility. The requirement of elongation in a 2-inch length usually found in sheet-metal specifications is not a reliable guide for predicting formability, because the elongation may not be uniformly distributed and may often be confined to an extremely small area. In a recent investigation at the National Bureau of Standards, an improved photo-grid technique for determining elongation of sheet metal has been developed, overcoming difficulties involved in other methods as well as providing a more reliable procedure for establishing the behavior of sheet metal during forming.[1] In addition, the new technique is proving useful at the Bureau in the investigation of plastic deformation in the vicinity of holes and in studies of other structural discontinuities that result in excessive stresses.

It has previously been suggested that the elongation over a gage length equal to the length of the bend or even approaching zero, corresponding to reduction in area, should provide a better basis for predicting sheet-metal formability. As the accurate determination of reduction in area is difficult for thin sheet, most attention has been directed to the measurement of elongation over short gage lengths.

A marked advance in the technique of measuring elongation over short gage lengths followed the development of the photo-grid process for ruling gage marks on test specimens by G. A. Brewer and R. B. Glassco.[2] In this process a negative is made from cross-section paper or a photoengraver's glass screen; the surface of the specimen is sensitized with bichromated photoengraving glue, exposed in contact with the negative, and rinsed with water. It is then dipped in dye to color the glue, which has been rendered insoluble by the exposure.

When the Bureau initiated the project, under the sponsorship of the National Advisory Committee for Aeronautics, to obtain stress-strain and elongation data for high-strength aluminum-alloy sheet used in aircraft, an accurate grid having spacings of about 0.01 inch was desired. It was found that existing grids were not suitable for accurate work because of excessive width of lines, inaccurate spacing, or lack of sharpness of the lines when examined at high magnification.

To meet this need, a master grid was prepared at the Bureau by ruling the grid in wax on plate glass, etching the lines in the glass, and filling them with lead sulfide. The grid, 2.07 by 2.16 inches over-all, was ruled by B. L. Page of the Bureau's Length Section and was etched and filled by E. J. Stovall of the Photographic Technology Section. These lines are about 0.015 millimeter wide

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[1] For further technical details, see NACA Technical Notes No. 1010, 1385, 1512, and 1513, by James A. Miller, available from the National Advisory Committee for Aeronautics, Washington 25, D. C.

[2] Determination of strain distribution by the photo-grid process, J. Aero. Sci. **9**, No. 1, 1 (1941).

and are spaced nominally 0.25 millimeter apart. A careful study of a negative obtained from the master grid by contact printing indicated that in the middle portion, where the lines are most accurate and where measurements are taken at each line, the spacing was within ±1 percent of the nominal value.

In the past investigators have experienced much difficulty in obtaining consistently satisfactory lines by using photoengraving glue. In particular, the lines are not clean-cut, and the time needed for exposure is quite variable. Lines of excellent quality were obtained at the Bureau, however, with the photoengraver's product known as cold top enamel.

The procedure developed by the Photographic Technology Section for printing lines on tensile specimens is as follows: The specimen, thoroughly cleaned of grease and other foreign matter and wiped with alcohol or acetone, is mounted on a whirler and coated with a small amount of cold top enamel. The whirler is then run at about 500 rpm for 10 minutes, or until the enamel on the strip is dry. The sensitized specimen is removed from the whirler and printed in contact with the film negative of the grid in a vacuum frame. A 4-minute exposure at about 12 inches from an EH-4 mercury flood lamp has generally proved satisfactory. However, the time of the exposure is affected by the relative humidity—the enamel becoming less sensitive with higher humidity. Also, the sensitized specimen should be exposed and developed immediately, since it will keep but a short time. The image is developed by immersing the specimen in agitated cold top developer (purple shade preferred) for about 20 to 40 seconds.

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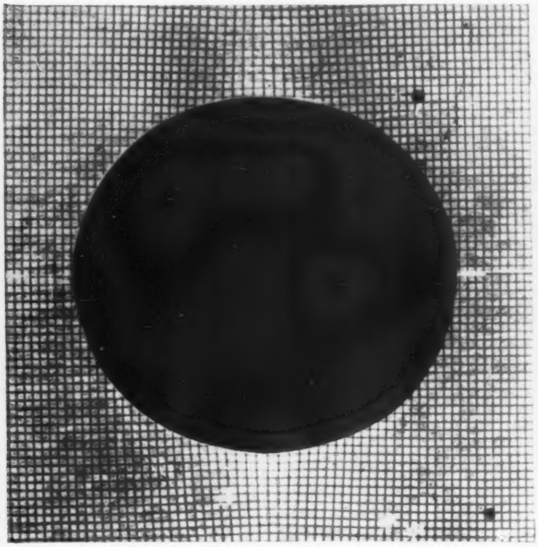
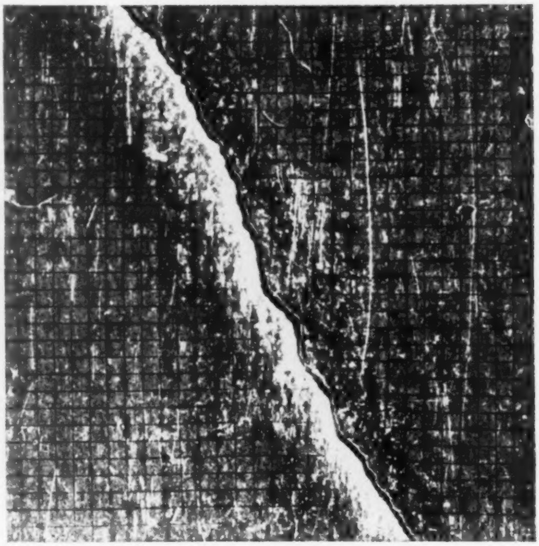
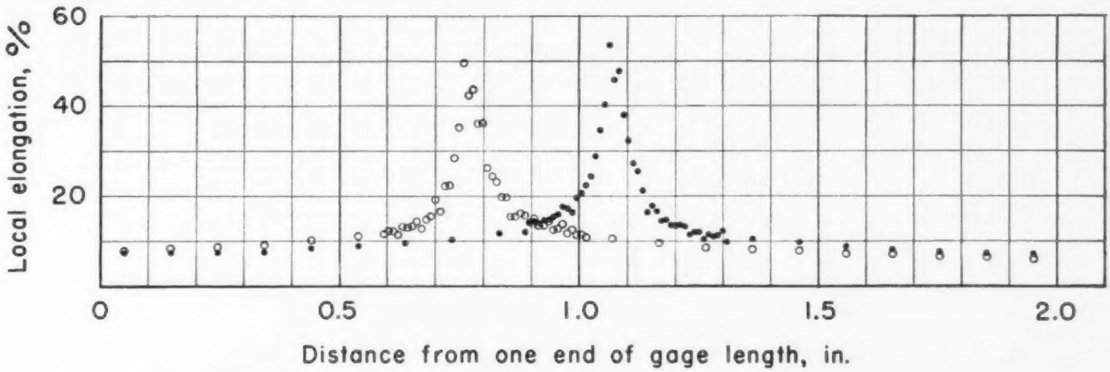




By means of a new photo-grid technique, plastic deformation in the vicinity of a hole (left) or fracture (right) can be readily examined. The extremely accurate grid lines are applied to a metal specimen before tension test by a photographic process. Localized elongation of the metal is revealed by distortion of the grid lines.

Graphs obtained through use of the new photo-grid technique for sheet metal elongation measurements show the local elongation measured on two 75 S-T aluminum-alloy sheet specimens loaded in tension in the direction of rolling. The peak values of about 50 percent for local elongation occurred in the vicinity of the fracture. Elsewhere the elongation was of the order of 10 percent or less.



A dye incorporated in the developer makes the image on the metal visible. After developing, the specimen is quickly rinsed for a few seconds in two baths of alcohol (95%) and immediately dried in air. The sensitizing and developing should be done in a dark room illuminated for ordinary photographic work.

Since the film negative does not maintain its dimensions during processing and during changes in relative humidity and temperature, a length equal to 50 or 100 spaces near the middle of the gage length of the specimen is measured to determine the average grid spacing. The measurements before and after test are made with a toolmakers' microscope under a 50 or 100 magnification reading to 0.001 millimeter.

Thermal Properties of Wind-Tunnel and Jet-Engine Gases

A project for the compilation of tables of thermal data on wind-tunnel and jet-engine gases has been established at this Bureau with the cooperation of the National Advisory Committee for Aeronautics. At present this program calls for the critical evaluation of available data and the preparation of convenient tables of 13 different thermal properties for each of 13 gases. However, additions both to the list of gases and to the properties to be tabulated are anticipated as the project continues.

Recent advances in jet propulsion and high-speed flight have emphasized the importance of accurate thermal data on the gases which flow through wind tunnels or jet engines, or which a guided missle must encounter in the atmosphere. In designing a jet engine, for example, it is desirable to know the composition of the products of combustion, the effect of the operating temperature on the efficiency of the engine, and the temperature that the walls of the engine will have to withstand. Information of this kind cannot be obtained unless reasonably accurate thermal data are at hand.

Thermal data for the region near room temperature and 1 atmosphere pressure are usually available, although they are not always easy to locate or in convenient form for use. But as the interval from room temperature increases, information of this kind becomes more scarce, so that above 900° or 1,000° K these data, especially for the nonequilibrium properties such as viscosity and thermal conductivity, are practically nonexistent. A similar situation exists at the higher and lower pressures. In view of the lack of readily available thermal data, the National Bureau of Standards was requested to make a critical compilation of existing published and unpublished data in convenient form for application. A tentative plan for the tables was first submitted to a large number of laboratories and individual scientists for comments and suggestions. After these had been received and considered, a program was evolved which during the past year has resulted in the preparation of 16 tables. Three tables are now available for general distribution.[3]

The tables as now planned will contain thermal data on the following gases: dry air, moist air, steam, hydrogen, oxygen, nitrogen, carbon dioxide, carbon monoxide, nitrogen dioxide, nitric oxide, helium, freon 12 (CF_2Cl_2), and argon. The properties to be tabulated, in general as functions of both temperature and pressure, are heat capacity at constant pressure, enthalpy (total heat), entropy, Gibbs free energy, compressibility factor, density, ratio of specific heats, velocity of sound, relaxation parameters, viscosity, thermal conductivity, Prandtl number, and vapor pressure. The data will cover a range from low pressures up to 100 atmospheres, and from very low temperatures, such as occur

[3] Correspondence regarding the tables should be addressed to Joseph Hilsenrath, Heat and Power Division, National Bureau of Standards, Washington 25, D. C. Suggestions for the extension and improvment of the tables are desired, as well as information regarding unpublished data.

in high-speed wind tunnels, to 3,000 ° K—a temperature encountered in jet engines and at the wing surfaces of high-speed aircraft. The information given is to be based in part on calculations and experiments carried out at the Bureau as well as on published and unpublished data from other sources.

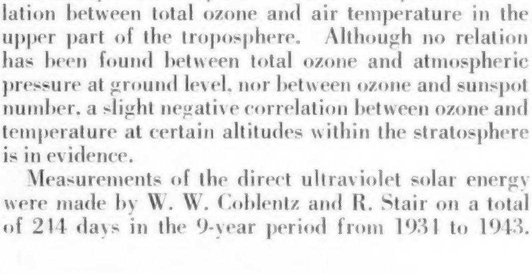
In the preparation of the tables, emphasis is placed on convenience for use. To make them equally adaptable to calculations in aerodynamics, heat transfer, and jet-engine problems, they are, wherever practical, expressed in dimensionless form. Clearly labeled conversion factors are then given on the same page with the table, permitting a quantity obtained from the table to be expressed in any desired units.

So far it has been possible to keep each table to a length of four pages or less. The tables are in loose-leaf form with a brief text containing a description of the table, directions for use, and an evaluation of the data upon which the table is based. Suitably qualified estimates of the accuracy of the tables are given, even though these estimates must sometimes be very approximate. In some cases a graph is included that shows the agreement between the table and the principal experimental data. Such a graph can quickly give the user of the table an idea of its accuracy that he could otherwise get only from hours of study of the original papers. A numbering scheme has been adopted that identifies both the substance and the properties treated in the table. For example, in Table 9.50, the "9" indicates that the substance is oxygen, and the "50" shows that the property tabulated is vapor pressure. Some of the tables are also available on IBM punched cards.

Total Ozone Related to Troposphere Temperatures

Long-term measurements of the ultraviolet radiation reaching the earth from the sun have revealed an important correlation between the temperature of the air at an altitude of about 5 miles and the total amount of ozone in the atmosphere. The ozone concentration varies with the seasons from a minimum in late summer to a maximum in late winter and has long been believed to have a direct relationship with the weather itself. A comparison of ozone measurements over a 9-year period at Washington, D. C., with weather and sunspot data for the same period by Ralph Stair of the Bureau's radiometry laboratory has revealed a very close correlation between total ozone and air temperature in the upper part of the troposphere. Although no relation has been found between total ozone and atmospheric pressure at ground level, nor between ozone and sunspot number, a slight negative correlation between ozone and temperature at certain altitudes within the stratosphere is in evidence.

Measurements of the direct ultraviolet solar energy were made by W. W. Coblentz and R. Stair on a total of 214 days in the 9-year period from 1931 to 1943.



Total ozone values are obtained through measurements of the direct ultraviolet solar energy reaching the surface of the earth. A titanium phototube (shown here with light shield and shutter) sensitive to radiant energy in the 3,000-Angstrom region is used in conjunction with glass filters whose transmittance increases with wavelength.

The observations were ordinarily made only on clear days with little smoke or haze, and the measured ultraviolet radiation passed through air masses of less than 1.5 atmospheres, except during the winter months when the sun was low in the southern sky. The radiation was measured with titanium phototubes sensitive to radiant energy in the wavelength region between 3,000 and 3,400 Angstroms, and with glass filters whose transmittance increases with wavelength. Ozone readily absorbs ultraviolet, and any change in the relative amount of ozone in the atmosphere will be accompanied by a change in the observed transmittance of the filters.

Although there are large fluctuations in the short ultraviolet emission from the sun, associated with sunspots and other solar activity, the relative spectral energy distribution in the 3,000-Angstrom region is assumed to remain constant, and fluctuations in solar emission are neglected in determining the total amount of ozone at any particular time. Ozone concentrations were determined on the basis of a calculated energy distribution curve of intensity versus wavelength for the solar radiation reaching the outer envelope of the earth's atmosphere. Measurements of solar energy have been made by many observers, but in most cases the data do not include the region near 3,000 Angstroms. Preliminary results obtained from rockets offer great promise for future work, but additional rocket studies are needed to establish the measurement of ozone concentration on a firm basis. The presently available data give only the upper envelope of the solar intensity curve and do not include the dips due to Fraunhofer absorption lines. Meanwhile, it is necessary either to assume or to calculate a solar energy curve for the ultraviolet region. The curve used in the present work was obtained by a phototube and filter integration method and may not be precise with regard to specific features, since it is simply the smooth curve which best fits the experimental data.

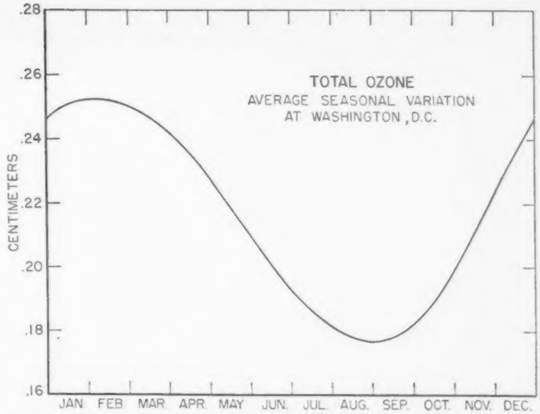
From an anlysis of the ozone measurements it appears to be impossible to establish any definite connection between pressure patterns and ozone value, but there is

some relationship between air movements and ozone. The variation of ozone with the seasons may be accounted for on the basis of temperature changes at the tropopause—the boundary layer between the low-lying troposphere and the stratosphere—which cause it to rise in the spring and drop again in the fall. In the troposphere, air movements by convection tend to take place vertically, whereas in the stratosphere the air is stratified into horizontal layers, and there is little vertical circulation.

Curves on vertical distribution of ozone and measured air temperature as a function of altitude indicate a close relationship between normal atmospheric characteristics and the position of the ozone band. Very little ozone normally exists within the troposphere, since air currents rapidly bring it into conditions of pressure and temperature that accelerate its degeneration. On the other hand, ozone fluctuations within the upper 10 percent of the ozone layer are rapidly brought to equilibrium as the result of normal photochemical reactions.

The experimental results show very little ozone below the tropopause. Temperature irregularities in the lower part of the atmosphere would therefore not be expected to affect the amount of ozone directly. But when a disturbance occurs at a much higher level, resulting in a change in the effective position of the tropopause, fluctuations in the ozone value would be expected. An analysis of the observed relationship between the amount of ozone and the temperature at various altitudes does in fact indicate that ozone changes are directly associated with air movements above about 4 or 5 miles. Vertical motion of the air at these levels changes the temperature below and above the tropopause and shifts the tropopause level as well. Similar effects are produced by a lateral influx of air from other latitudes. The relative importance of these two types of air movements in increasing or decreasing the amount of ozone at any particular location has not yet been determined. Both vertical and lateral air movements have been observed in the trails left by meteors at high altitudes.

The probable existence of a dip in the daily ozone curve beginning at noon and persisting into the afternoon is an interesting result of these investigations. The noon dip is not large, but it is nearly always present in the ultraviolet measurements made in Washington



In this curve the amount of ozone is expressed in terms of the thickness of a fictitious layer of ozone equivalent to the actual ozone distributed throughout the atmosphere. The ozone concentration varies from a minimum in late summer to a maximum in late winter.

as well as in the mountain and desert locations using the same or similar instruments. The extent of the noon dip in the resulting curves depends upon the particular solar energy curve employed in the calculations. To suppress it entirely would require the use of a solar energy curve for the spectral range of 3,100 to 3,400 Angstoms, considerably steeper than the one now employed. This seems unjustified at present. Rather, it is reasonable to believe that the noon dip is real and that we should credit its existence to either a diurnal decrease in ozone or to some other variable atmospheric condition affecting the relative spectral transmittance of the atmosphere. Changes in size of water particles or amount of dust have been suggested as causes, but neither were present in appreciable quantities in the mountain and desert measurements. There seems to be no obvious relationship between apparent ozone value and local humidity or observable dustiness.

It is apparent from the careful analysis of these long-term data that all previous ozone work that used unknown or uncorrected temperature coefficients may be in error by a considerable margin. The close correlation between air temperatures and amount of ozone may also be significant in this respect.

Preparation and Revision of Building Codes

Organizations responsible for the preparation or revision of building codes will find many helpful suggestions and much information in a new booklet, *Preparation and Revision of Building Codes*, recently published by the National Bureau of Standards.

This booklet discusses principles and problems associated with building code requirements, gives sources of technical information and its applications, and reveals methods by which full advantage may be taken of new developments in materials and construction techniques. Subjects discussed include basic principles involved, methods of presentation, advantages of using national standards, and extent of delegation of authority to the building official.

Building Materials and Structures Report BMS116, *Preparation and Revision of Building Codes*, by George N. Thompson, 17 pages, is available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., for 15 cents a copy. Foreign orders must include an additional sum of one third the publication price to cover mailing costs.

The use of baseboard heating systems in low cost housing has increased in recent months, particularly in basementless houses where a first-floor heating system is necessary. In order to acquire adequate technical data on systems of this type, the Bureau included an investigation of a typical baseboard heating system [4] as part of its broad program on heat transfer phenomena in small houses. The tests covered the temperature distribution in a four-room test bungalow under various outside temperature conditions, in addition to the installation and operational problems involved. A study of the characteristics of two types of room-temperature controls with such a system was also made. In spite of certain inherent disadvantages, mainly the difficulty of fitting the system to the variable dimensions of conventional houses and the inability to control the heat output to individual rooms, the Bureau's results indicate that the baseboard heating system provides more comfortable environments in dwelling homes than many of the systems used in the past.

The various combinations of dry-bulb temperature, relative humidity, and air motion necessary to provide comfortable conditions in homes in the United States have been established by the American Society of Heating and Ventilating Engineers for convection heating. In practice, however, many heating systems provide regulation only of the dry-bulb temperature accompanied by a partial, indirect control of relative humidity and air motion in the living space.

The temperature differences from the floor to head level and from room to room are also important in judging the comfort provided by a heating system. Satisfactory uniformity is often difficult to attain with inexpensive heating systems. A great many small houses have been built in recent years with concrete floors laid

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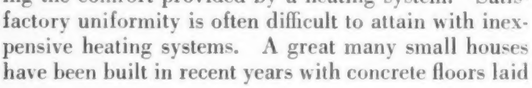
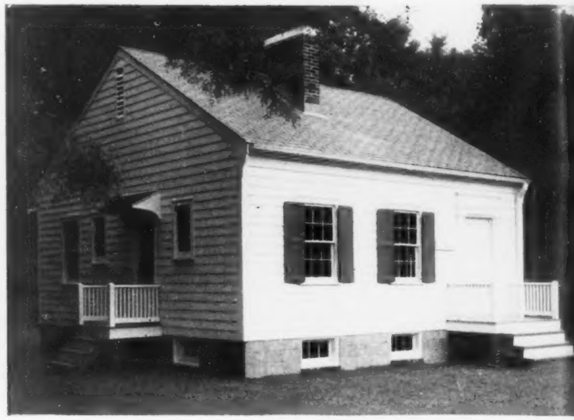
[4] For further technical details, see A Study of a baseboard convector heating system in a test bungalow, by Paul R. Achenbach and Edward M. Tierney, National Bureau of Standards Building Materials and Structures Report BMS115, available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. at 15 cents a copy.



A floor plan of the test bungalow includes the piping circuit and the location and size of the baseboard convector elements, as installed for a performance study of a typical baseboard heating system.

Performance of a ypi
Heating Sys



A test bungalow (left) has been constructed at the National B of S small houses. It has four rooms and a bath, with a small ce hallwa to obtain data upon which estimates can be made of the per nce o occupancy. The bungalow, built in compliance with FHA s ation structure (right) so that the temperature outside of the house main throughout the United States.

on the ground or with floors laid over shallow crawl spaces. This construction has necessitated placing the heating plant on the first floor in most cases and has eliminated any direct warming of the under side of the floor.

Several types of baseboard heating systems have been developed recently; some use hollow cast-iron elements, either finned or unfinned, and others have finned steel pipe or finned copper tubing with shields or covers partially enclosing the heating elements. These systems use elements not much thicker or higher than a baseboard around the entire perimeter of the living space. An additional advantage claimed for this type of system is that the heating elements are almost entirely removed from the useful living space.

The baseboard heating system installed in the test bungalow at this Bureau consisted of lengths of finned $1\frac{1}{4}$-inch iron pipe under the windows connected by unfinned 1-inch standard pipe and partially enclosed by a perforated sheet-metal cover. The fins were $3\frac{1}{2}$ inches square and were spaced $\frac{1}{4}$ inch apart on the pipe. Heat was transferred primarily by convection of air through the enclosure and over the finned surface. Hence the system has been termed a baseboard convector heating system.

Two types of controls were used for the tests: (1) A conventional wall-type electric thermostat and (2) a modulating control employing an outside thermostat and a three-way valve that mixed the boiler supply and return water to vary the temperature of the water entering the system.

f a ypical Baseboard
ting ystem

ional B u of Standards for research on heat transfer phenomena in nall ce hallway. Entire heating systems may be installed in order the per nce of these heating devices in similar homes designed for FHA s ations, has been completely enclosed within an insulated house e maintained at any temperature that might be encountered

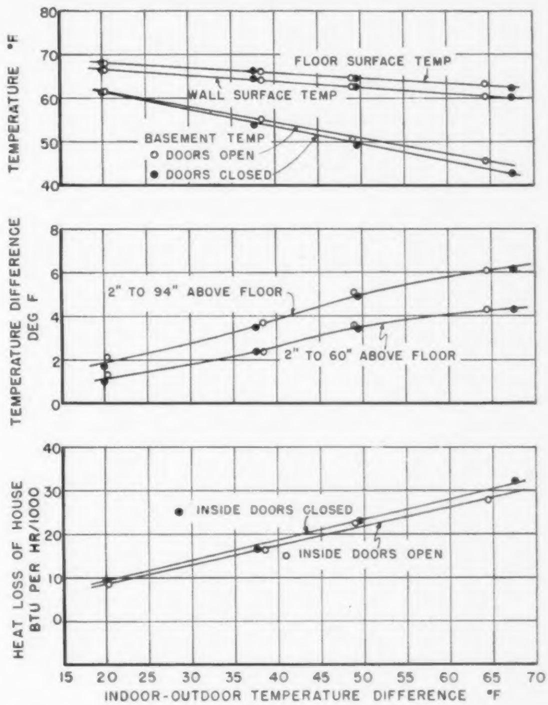
The Bureau's test bungalow, which conforms to FHA specifications for a low-cost house, is completely enclosed by an insulated outer shell so that the temperature may be varied to simulate any condition throughout the United States. It is of frame construction and has four rooms and a bath, which are connected by a hallway near the center of the house. There is a full basement under the living quarters, although this feature was not a consideration in the present tests. The outside walls of the structure are of conventional frame construction and consist of 2- by 4-inch studding with sheathing and lap siding on the outside separated by a layer of building paper. The inside wall finish consists of ½-inch plasterboard nailed directly to the studding. A double-wood floor is used with 1-inch rigid insulation nailed directly to the underside of the floor joists. The ceiling of the living quarters is ¼-inch plywood supported by frameworks of 2- by 4-inch members and covered by 3⅝ in. of rock wool insulation.

Temperatures were measured in the test bungalow by means of thermocouples supported by strings attached to the ceiling. Five strings of five thermocouples each were located in the kitchen, living room, and the two bedrooms with one string suspended at the center of each room and one midway between the center and each corner of these rooms. Three strings of five thermocouples each were used in the bathroom. The five thermocouples on each string were permanently installed at distances of 2, 30, 60, 78, and 94 inches above the floor.

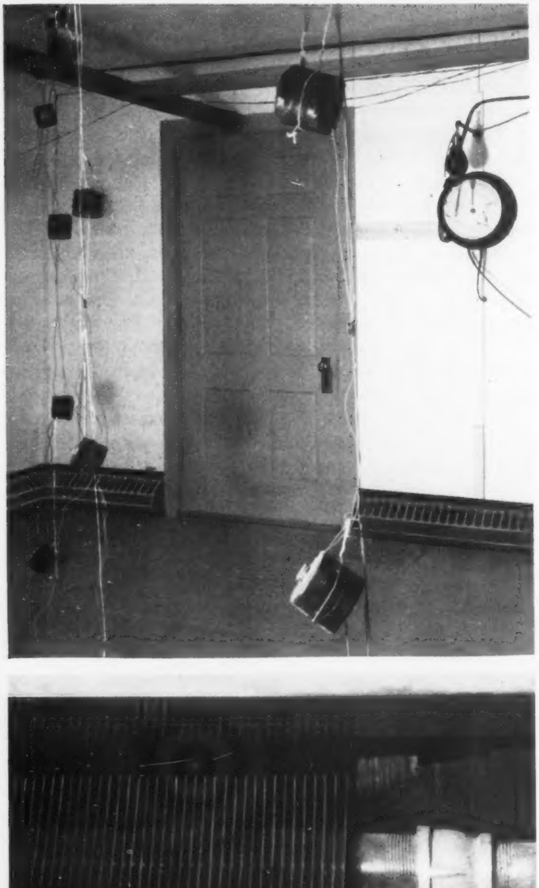
Other thermocouples were used to measure the temperatures outside of the bungalow, on the inside and outside surfaces of the exterior walls, on the floor surfaces, in the basement, in the attic, and at several places on the hot water pipe encircling the house.

The temperature distribution was observed in the bungalow while a temperature of 70° F was maintained at the 30-inch level for outside air temperatures of 50°, 32°, 20°, and as near 0° F as could be attained. In addition to the investigation of the temperature distribution in the four rooms with a steady outside temperature, the characteristics of the modulating valve and outdoor-thermostat control system were observed when the outdoor temperature was varied between 0° and 40° F as rapidly as the refrigerating system permitted.

The pickup characteristics of the baseboard convector system, when controlled by the outdoor thermostat, were also observed. The two bedrooms were cooled to 50° F by opening the windows, thus simulating the practice of many people who sleep with the bedroom windows opened. When the bedrooms reached a temperature of 50° F; the windows were closed, and the recovery of the temperature in the bedrooms was observed while the interior doors remained closed. The temperatures in the kitchen and living room and the



Graphs reveal the relation of heat loss, vertical temperature differences, basement temperature, wall surface temperature, and floor surface temperature to the indoor-outdoor temperature difference for the baseboard convector system with room-thermostat control.



Baseboard convector (top) in the living room of the test bungalow with the perforated metal housing in place. Strings suspended from the ceiling support five thermocouples at various distances from the floor. A close-up view of a finned convector element without the sheet-metal enclosure is shown below.

supply water temperature were also recorded during this transient condition.

The test results showed that comparatively small temperature differences existed between rooms and between different levels in the same room with this type of heating system for the range of outside temperature from 50° to 0° F. However, the temperature differences increased in magnitude both horizontally and vertically as the outside temperature decreased. The vertical temperature gradient ranged from 0.3 deg F per foot above the floor for an outside temperature of 50° F to 0.8 deg F per foot for an outside temperature of 0° F.

Temperature differences in a vertical direction were not appreciably affected by closing the doors. The

Temperature distribution produced by baseboard convector with room thermostat (inside doors open)

	Test number			
	1	2	3	4
Outside temperature, ° F	49.9	31.6	20.7	4.9
Heat loss of house, Btu/hr	8,650	16,280	22,410	27,970
Average room temperature, ° F:				
2 in. above floor	69.2	68.1	66.9	66.0
30 in. above floor	70.2	70.1	69.7	69.4
60 in. above floor	70.5	70.5	70.4	70.3
78 in. above floor	70.9	71.1	71.0	71.1
94 in. above floor	71.3	71.8	71.9	72.0
Vertical temperature difference, ° F:				
2 to 60 in. above floor	1.3	2.4	3.5	4.3
2 to 94 in. above floor	2.1	3.7	5.0	6.0
Basement temperature, ° F	61.7	55.2	50.7	45.9
Attic temperature, ° F	56.1	46.8	40.5	35.7
Floor surface temperature, ° F	68.0	66.3	64.9	63.3
Wall surface temperature, ° F	66.6	64.1	62.9	60.4

maximum temperature difference between any two rooms in the living zone [5] ranged from 0.7 deg to 1.4 deg F with the interior doors open and from 1.4 deg to 3.6 deg F with the interior doors closed for an outside temperature range of 50° to 0° F.

The heat loss of the test bungalow was found to be directly proportional to the difference in temperature between the inside air and the outside air, although the heat loss averaged about 5 percent greater when the interior doors were closed. This greater heat loss when the doors were closed was due primarily to overheating of the bathroom (used as a utility room).

The control of room temperature by the outdoor thermostat and modulating valve for rapidly changing outdoor temperature was observed. The results show that some overheating of the house occurred during periods of rapidly falling outdoor temperature and that some under-heating occurred during periods of rapidly rising outdoor temperatures. This phenomenon was to be expected because the temperature of the supply water was changed immediately in response to counter changes in outdoor temperature, whereas the inside air temperatures did not feel the effect of the outdoor temperature change for an hour or more because of the thermal lag of the exterior walls.

The pick-up of the bedroom temperature after night cooling was measured with the outdoor thermostat control, because consideration of the operating principle of this control suggested that it would provide slower pick-up than conventional room thermostat control. It was noted that 7 hours elapsed before the temperature in the north bedroom reached 70° F, and the temperature in the south bedroom did not approach a steady value of 68° F. for at least 9 hours after closing the windows. The temperature of the water supplied to the baseboard convector did not change appreciably when the windows were opened or during the pick-up period. A change in supply-water temperature was not to be expected with the outdoor thermostat control system, however, since the outdoor temperature remained constant.

[5] The space between levels 2 and 60 inches above the floor is called the "living zone" in this report.

The results of the Bureau's investigation showed that the specimen baseboard convector system produced lower vertical temperature gradients in the test bungalow than any other system or device that had been tested heretofore. Whereas a temperature difference of 8° F. was observed between the 2-inch and 60-inch levels for a gravity hot water heating system with conventional thin-tube radiators and the boiler in the basement, a temperature difference of 3.5° F. was observed between the same levels with the baseboard convector for an outside temperature of 20° F. in both cases.

The baseboard heating system is well suited for application to basementless houses because it is installed above the floor level and because it provides better comfort than most other systems at the floor level. However, this type of system can also be used in houses with basements with the boiler located below the floor.

Perforated Cover Plates for Steel Columns

A study of the mechanical properties of perforated steel cover plates for bridge columns, utilizing full scale models, has been completed by the National Bureau of Standards. The work, carried out over a period of years in cooperation with the American Institute of Steel Construction, consisted of investigations of the cover plates with respect to stress distribution, strength, and axial stiffness. Experimental results proved to be in close agreement with theoretical predictions and provide engineers with a rational approach to the design of bridges using cover-plate columns.

Most large compression members of bridge trusses have a box-type cross section in order to provide efficient utilization of the material in resisting column action. It is desirable to provide openings in the member to allow access to the interior for inspection and painting; common practice is to use two channels (or four angles and two web plates) with a cover plate on one side and lattice bracing or battens on the other. The lattice bracing or battening serves to brace the flanges of the channels or angles and to transfer shear so that the full moment of inertia of the remainder of the cross section is developed, but it does not contribute to the cross-sectional area effective in resisting thrust. Recently a more economical design in which the bracing is replaced by a perforated cover plate has been used. The purpose of the Bureau's investigation, which was conducted in the engineering mechanics laboratory under the direction of Dr. A. H. Stang, was to determine the effects of the perforations on the structural properties of these plates.

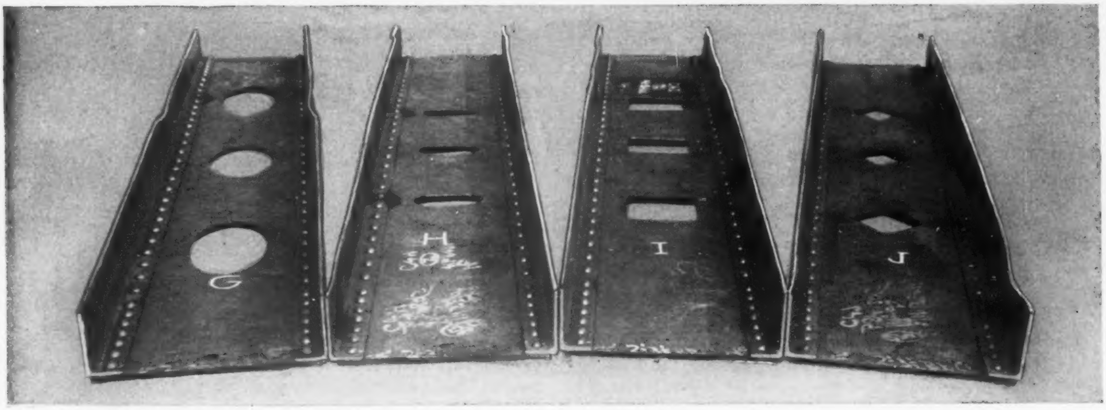
Tests in the elastic range have been made on columns with plates having circular, ovaloid, elliptical, and square perforations, as well as on columns with solid plates. Maximum compressive-load tests have also been made on these columns. In order to limit the investigation to a reasonable number of columns, it was decided to use cover plates of only one thickness, namely, $\frac{3}{8}$ inch, and to use 8- by 4- by $\frac{1}{2}$-inch steel angles with the plates to complete the columns. The plates and angles were of open-hearth low-carbon steel. The cover plates were 15, 20, $25\frac{1}{2}$, and 30 inches wide and 14 feet 9 inches long. Columns for the tests were made with each type of perforation in each width of cover plate. In addition, three different spacings of the perforations were used. For control, three unperforated plates of each width were made into columns to be tested.

Both perforated and unperforated plates were subjected to compressive tests in the elastic range with two angles or with four angles bolted to them. After these tests were completed, specimens consisting of a plate and two angles riveted together were subjected to maximum compressive load tests.

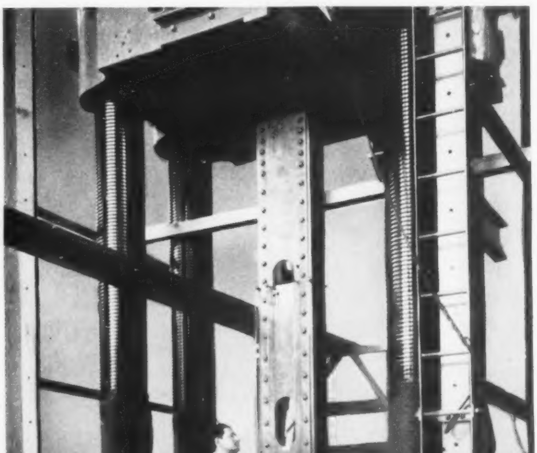
The axial stiffness was measured on each column in a 600,000-pound-capacity testing machine by using compressometers having a gage-length equal to the length of the perforated plate between the centers of two perforations, and, for the unperforated plate columns, not less than one-third the length of the column. Corrections were made to allow for changes of temperature. Strain readings were taken at two loads—at a small initial load and at the largest load for the determination of the modulus. Calculations of stiffness according to theory are in good agreement with the experimental values, differing, except for a few scattered values, by not more than ±0.02 in rigidity factors ranging from 0.82 to 0.96. The general tendency is for the experimental values to be less than the theoretical.

For many of the columns, the complete stress distribution over the middle bay of the cover plate was obtained from hand strain-gage readings. A novel feature of this work was the arrangement of the rosettes. Strain-gage holes for 2-inch gage lengths were drilled

Perforated cover plates are used in bridge columns, such as those in the Delaware River Bridge from Easton, Pa., to Phillipsburg, N. J., to provide openings for inspection and painting and for a more economical design. A study of the mechanical properties of these cover plates has been carried out at the Bureau in cooperation with the American Institute of Steel Construction.



Full-scale specimens of the perforated steel cover plates were subjected to various mechanical tests to determine their structural properties. For example, the effects of the maximum load test are demonstrated by four columns made up with typical perforations: (left to right). Elliptical, load parallel to major axis; ovaloid, load parallel to short axis; square, load parallel to side; and square, load parallel to diagonal. The column on the left failed toward the plate side, whereas the other three columns failed away from the plate side, as would be expected from the consideration that in the neighborhood of a perforation, the gravity axis of the column is displaced away from the plate side.


Data on such properties as axial shortening, deflection at midheight of the column, and the maximum load were obtained from the maximum load test in the Bureau's large-capacity testing machine. Note the compressometers on the column.

on both sides of the plate in a continuous equilateral-triangular pattern so that each hole (except those near edges) served for six gage lines. This arrangement provides uniform coverage of the area with a minimum of gage holes and readings. Very careful jigging of the holes was required to keep all of the gage lengths within the small range of the Whittemore strain gages used. From the data obtained, all of the elements of the stress distribution were computed and presented graphically as isograms of the principal stresses and their directions.

The distribution of stress on the edge of the perforation at mid-height of each column was obtained from strain-gage readings taken by hand. These stresses were compared with values computed from a theory derived by Martin Greenspan of the Bureau staff, in which an exact solution to the problem is obtained for a hole having any boundary of which the equation can be expressed in certain parametric forms. In general, the agreement between theory and measurements is good, although in many cases the measured stress exceeds the theoretical value at the position of maximum stress.

Twenty-four two-angle columns, as well as four controls (solid plates) were tested to destruction. Most of the columns failed by bending away from the plate side, as would be expected because of the local eccentricity near a perforation.

This work indicates that perforated cover plates contribute to the strength, and especially to the stiffness, of columns built up from the plates and angles. Formulas have been derived that may be applied whenever data are required concerning displacements in a structure having perforated members, and the validity of these formulas has been confirmed by experiment. At the same time it has been found that the net area of a perforated-plate column may safely be used for design purposes, even for a perforation shape that produces great stress concentration.

Very Thin Crystal Oscillator Plates for High Frequency Use

The increasing interest in high frequencies for radio communication is accompanied by a demand for very thin quartz crystal oscillator plates having fundamental frequencies up to 100 megacycles or even higher. The usual crystal grinding methods and machinery, however, have proved inadequate for producing plates of the required thinness. In the course of an invesitgation of this problem, L. T. Sogn and W. J. Howard of this Bureau have modified conventional techniques to overcome these difficulties.[6] The improved equipment, capable of producing 0.001 inch thick quartz crystals with a high degree of parallelism and flatness, can also be used for grinding equally thin wafers from a variety of other materials. A promising application, for example, is the production of extremely thin dielectric plates for miniature radio condensers.

In crystals whose fundamental frequency is in the higher range, the thickness of the quartz plate determines the frequency. Since the frequency is inversely proportional to the thickness, the higher the frequency the thinner the crystal must be. For example, a crystal with a fundamental frequency of 100 megacycles is about 0.001 inch thick. Moreover its surfaces must be parallel within a few millionths of an inch. To manufacture such crystals it has been necessary to modify the usual lapping procedures and to design equipment suitable to the modification.

Ordinarily, crystals are carried in a planetary path between two abrasive-charged lapping plates by a thin apertured disk called a nest. Nests thinner than 0.005 inch do not have the strength required to carry the crystals. Because the nest must be thinner than the crystals to permit their abrasion, crystals produced by this method have maximum fundamental frequencies of about 20 megacycles.

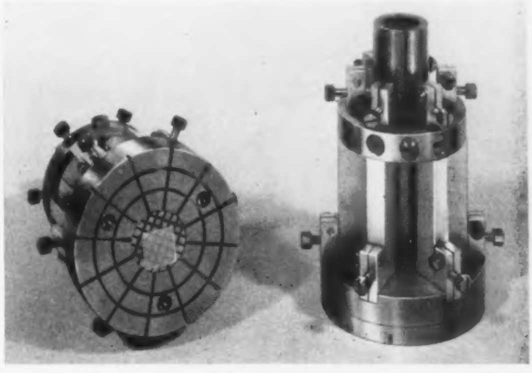
The initial problem, therefore, was to make the crystal thickness independent of the nest thickness. The solution involved various replacements for the customary top lapping plate and related changes in the design of the nest.

In the first modification, the crystals were individually cemented to small steel blocks that were used in place of the top plate to supply lapping pressure. A conventional nest carried the cemented units over the lower lap. Because of difficulties inherent in this method of mounting, the crystals became wedge-shaped. Crystals were next lapped, using the same equipment with the pressure blocks resting freely on the crystals. This process however did not correct contour defects, and the rate of lapping had to be reduced to prevent the blocks from being separated from the crystals.

To permit faster lapping with some control of the movements of the block and crystal relative to each other, both were closely confined in an accurately machined opening of a small steel plate. When this assembly was carried by the nest through the lapping operation, abrasives that worked into the narrow clearance between the block and plate caused binding. For this reason the plate opening was enlarged, and the pressure block was centered by means of an apertured zinc sheet cemented to the top side of the retaining plate, thus eliminating binding and permitting the crystal to move laterally with respect to its pressure block. Although crystals lapped this way were wedge-shaped, eperience that led to more successful models was gained.

The wedge-shaped crystals emphasized the need for designs that would assure parallelism. The attacks on this phase of the problem resulted in three variations of a model in which small blocks were rigidly attached to a lapped ring. The assembled blocks were trued against the lap until they were coplanar and parallel to the lap so that wedged crystals could be corrected by parallelism. To prevent uneven abrasion caused by the adhesion between the crystals and the blocks, the surfaces of the latter were broken up by cross-channels. In the first apparatus of this type, pentagonal blocks fitted into pentagonal nest openings. In the second variation, cylindrical plugs were used, and the nest was eliminated by using a close-fitting collar around each plug to confine its crystal and by using spokes to drive the ring directly. The third variation was similar to the first, except that round rather than pentagonal plugs and holes were used, and its nest was thicker and channeled to reduce sticking.

Of the three forms just described, the nestless type was least satisfactory, chiefly because its excessive weight caused breakage. The third variation gave better results than the first because the plugs and holes



The tall plunger apparatus eleminates limiting factors of conventional lapping equipment in producing very thin quartz crystals. In this modification of the inkwell model, bearing-point screws replace the close fitting bore. Note quartz crystal in position for grinding.

[6] For further technical details, see The mechanical production of very thin oscillator plates, by L. T. Sogn and W. J. Howard, J. Research, NBS, 43 (Nov. 1949) RP2037.

were a more precise fit. Consequently, crystals produced with the round plugs had less pronounced rims. Deviations from parallelism in crystals produced by both lapping units were radial rather than wedge-like. The rims accounted for most of the deviation, which did not exceed 0.00004 inch.

Because of the difficulty in removing the ring and handling very thin crystals, a lapping method that permits much easier inspection of individual crystals has been evolved. The apparatus employed is an improved form of the square block and cell method and exists in two slightly different models—the inkwell and the tall plunger. The inkwell type has a conical exterior and is essentially a keyed and closely fitting plunger and cylinder. The crystal is attached to the plunger by means of a drop of oil; the unit is then inverted and placed on the lapping plate. The crystal is thus confined between the piston and plate by the cylinder walls. A nest drives a number of such units over the lapping plate. The tall plunger model differs mainly in having a taller piston sliding on bearing screws by which the amount of wobble can be precisely controlled.

Crystals have been lapped at the Bureau to 0.001 inch with both these models. Breakage is almost nonexistent, and the surfaces are quite flat and parallel. The limiting thickness for this quipment is not yet known, since the difficulties of handling and properly measuring such crystals impose many new problems that remain to be solved.

NBS Publications

Periodicals [7]

Journal of Research of the National Bureau of Standards, volume **43**, number 3, October 1949. (RP2029 to RP2033, inclusive.)

Technical News Bulletin, volume **33**, number 10, October 1949. 10 cents.

CRPL–D61. Basic Radio Propagation Predictions for January 1950. Three months in advance. Issued October 1949. 10 cents.

Nonperiodical [7]

Research Papers [7, 8]

RP2020. Ultra-microtomy by a new method. Sanford B. Newman, Emil Borysko, and Max Swerdlow. 10 cents.

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RP2022. Seasonal variation of ozone at Washington, D. C. Ralph Stair. 10 cents.

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Building Materials and Structures Reports [7]

BMS116. Preparation and revision of building codes. G. N. Thompson. 15 cents.

Circulars [7]

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C480. Fundamental techniques in the frequency adjustment of quartz crystals. Leland T. Sogn and Catherine Barclay. 10 cents.

C481. High-frequency voltage measurement. Myron C. Selby. 20 cents.

C482. Bibliography of books and published reports on gas turbines, jet propulsion, and rocket power plants. Ernest F. Fiock. 20 cents.

Commercial Standards [7]

CS117–49. Mineral wool insulation for heated industrial equipment. (Second edition. Supersedes CS117–44.) 15 cents.

Handbooks [7]

H43. Installation and maintenance of electric supply and communication lines: Safety rules and discussion. $1.50.

Articles by Bureau Staff Members in Outside Publications [9]

On the reality of zero of Bessel functions. Abraham Hillman. Bull. Am. Math. Soc. (531 West 116th Street, New York 27, N. Y.) **55**, 198 (1949).

Measurement of the dielectric constant and loss of solids and liquids by a cavity perturbation method. George Birnbaum and Jacques Franeau. J. Applied Phys. (Case Institute of Technology, Cleveland 6, Ohio) **20**, 817 (1949).

On backflow of a viscous fluid in a diverging channel. Milton Abramowitz. J. Math. and Phys. (Massachusetts Institute of Technology, Cambridge 39, Mass.) **28**, 1, (April 1949).

Note on the expansion of confluent hypergeometric functions in terms of bessel functions of integral order. Meyer Karlin. J. Math. Phys. **28**, 43 (April 1949).

Coefficients for repeated integration with central differences. Herbert E. Salzer. J. Math. and Phys. **28**, 54 (April 1949).

Determination of the density of UF_6 from the sinking temperatures of glass floats. Harold J. Hoge and Martin T. Wechsler. J. Chem. Phys. (57 East Fifty-fifth Street, New York 22, N. Y.) **17**, 617 (1949).

Measurements of the proton moment in absolute units. H. A. Thomas, R. L. Driscoll, and J. A. Hipple. Phys. Rev. (Univerity of Minnesota, Minneapolis 14, Minnesota) **75**, 902 (1949).

Determination of e/m from recent experiments in nuclear resonance. H. A. Thomas, R. L. Driscoll, and J. A. Hipple. Phys. Rev. **75**, 992 (1949).

Mass spectrometry. J. A. Hipple and Martin Shephard. Anal. Chem. (1155 Sixteenth Street, NW, Washington 6, D. C.) **21**, 32 (1949).

Analysis of recycle styrene. A. R. Glasgow, Jr., N. C. Krouskop, V. A. Sedlak, C. B. Willingham, and F. D. Rossini. Anal. Chem. **21**, 688 (1949).

[7] Send orders for publications under this heading only to the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Annual subscription rates: Journal of Research, $4.50 (foreign $5.50); Technical News Bulletin, $1.00 (foreign $1.35); Basic Radio Propagation Predictions, $1.00 (foreign $1.25). Single copy prices of publications are indicated in the lists.

[8] Reprints from September Journal of Research.

[9] These publications are not available from the Government. Requests should be sent direct to the publishers.

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